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Improving Mechanical Properties of Nanocomposite Coatings: Potential uses in Bone Tissue Scaffold Applications

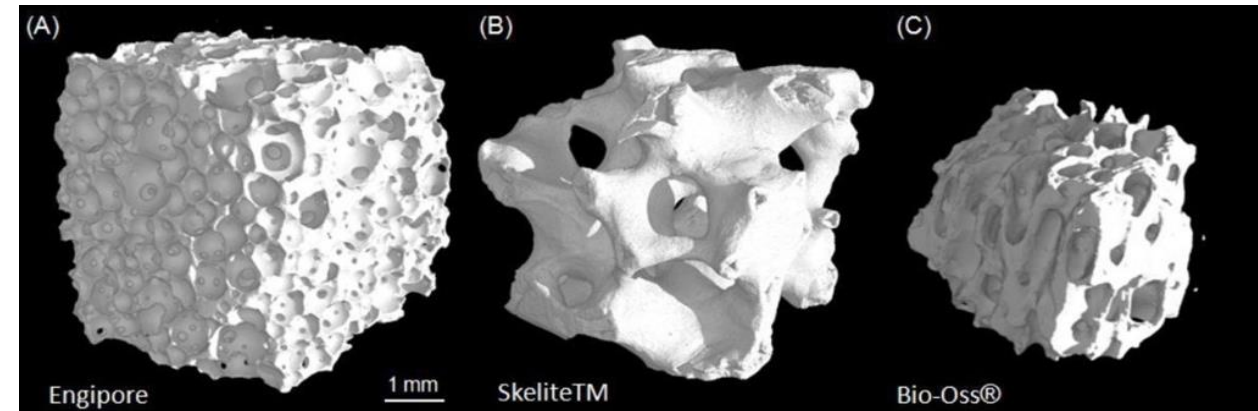
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- Tissue engineering solutions are an attractive alternative to autograft treatment for bone trauma patients
- Bone tissue scaffold development has challenges:-
 - High porosity in conjunction with suitable mechanical properties



Tailor mechanical properties of bone tissue scaffolds via thin film nanocomposite coating

[Image] Alessandra Giuliani, Synchrotron Radiation and Nanotechnology for Stem Cell Research, Stem Cells in Clinic and Research, 2011

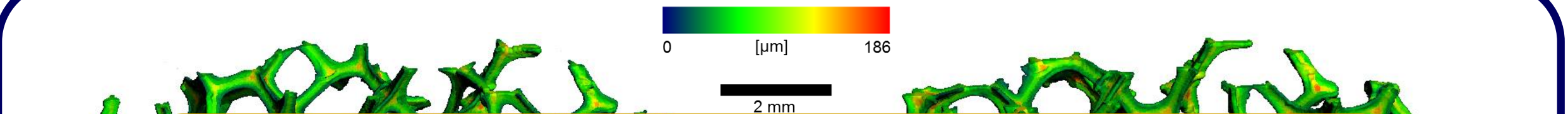
INTRODUCTION

MATERIALS AND
METHODS

RESULTS

CONCLUSIONS

FUTURE WORK



Coating has only been tested under ambient conditions. Testing must be done when submerged to examine efficacy under hydrated conditions

Un-coated

100 μm

Coated

100 μm

“Brick-by-brick”

Ziminska et al. ACS Appl Mater Interfaces. 2016;8(34):21968–73.

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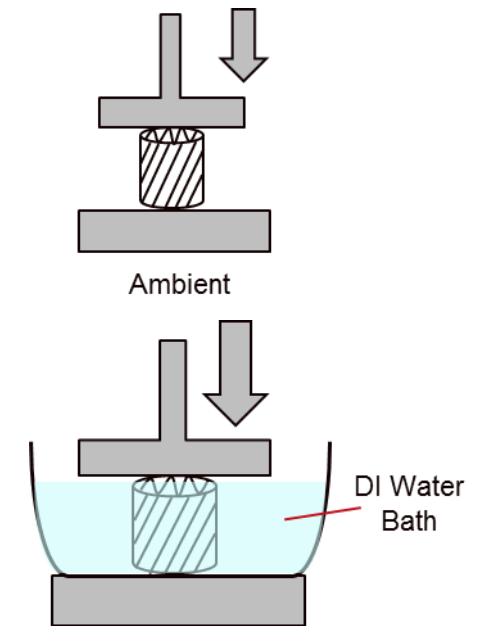
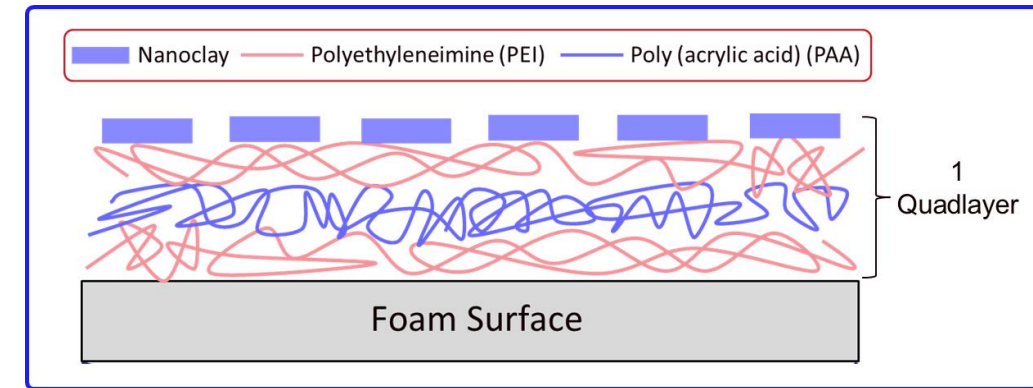
FUTURE WORK

Materials

- Open cell polyurethane foam
- Coated with varying number of quadlayers of:
 - » Poly(ethyleneimine)
 - » Poly(acrylic acid)
 - » Cloisite Na⁺ nanoclay

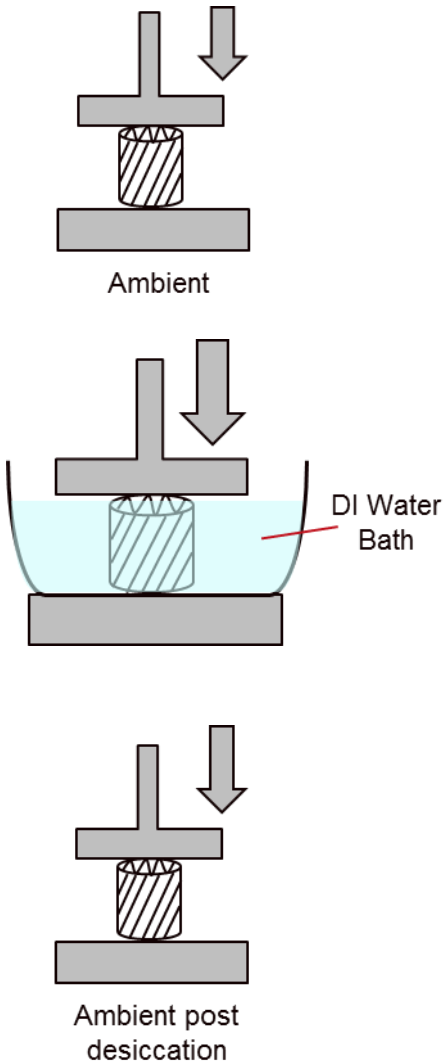
Methods

- Tested under uniaxial compression in the elastic range at:
 - » Preload of 0.03 N
 - » Crosshead speed of 2.0 mm/min
 - » Deformed to 6% of strain
- Under ambient conditions ($\approx 30\%$ RH, 21 °C)
- Under DI water (100% RH, 21 °C)

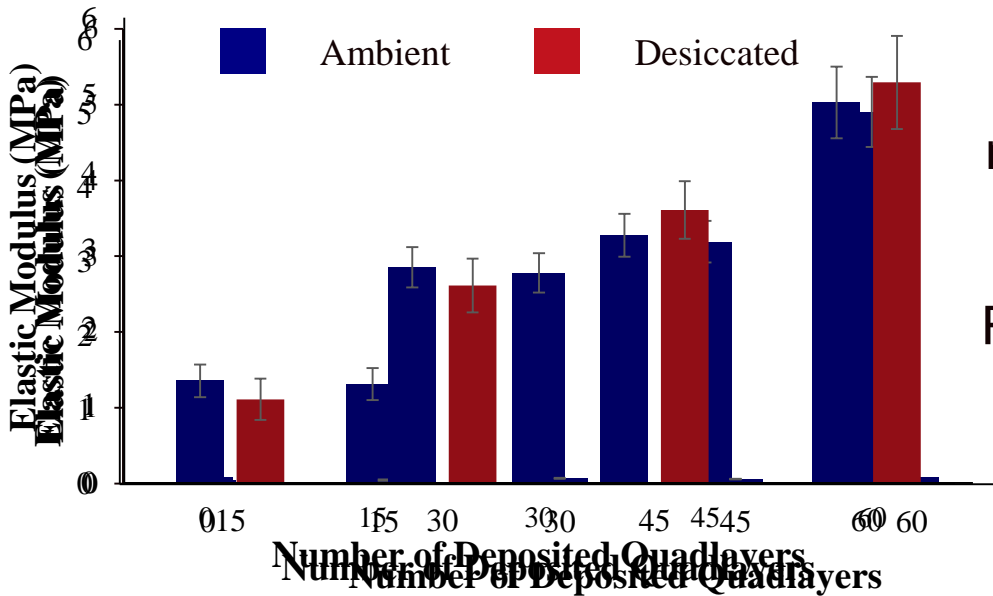


Coated Foams Hydrated Testing

(n=5)

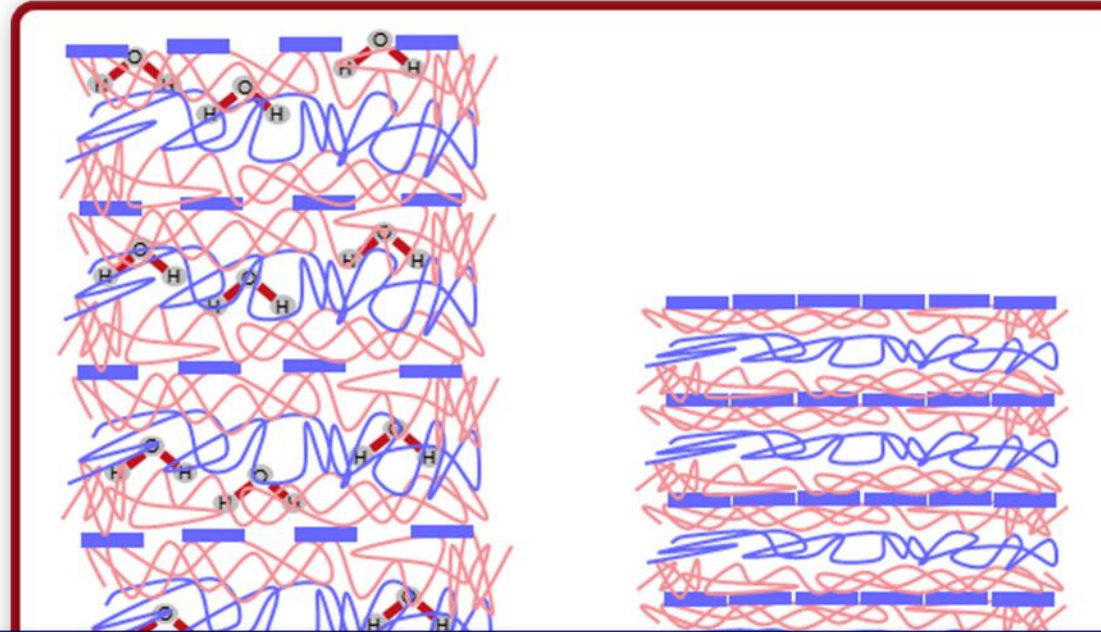


Quadlayers	Average Elastic Modulus (MPa) \pm SD			
	Ambient	In Water	In Water 1 Hour	Desiccated
0	0.08 \pm 0.00	0.05 \pm 0.00	0.05 \pm 0.01	0.10 \pm 0.01
15	1.31 \pm 0.21	0.06 \pm 0.01	0.06 \pm 0.01	1.08 \pm 0.27
30	2.78 \pm 0.26	0.08 \pm 0.01	0.08 \pm 0.01	2.54 \pm 0.35
45	3.19 \pm 0.28	0.07 \pm 0.01	0.07 \pm 0.00	3.52 \pm 0.37
60	4.9 \pm 0.46	0.10 \pm 0.01	0.09 \pm 0.01	5.17 \pm 0.60



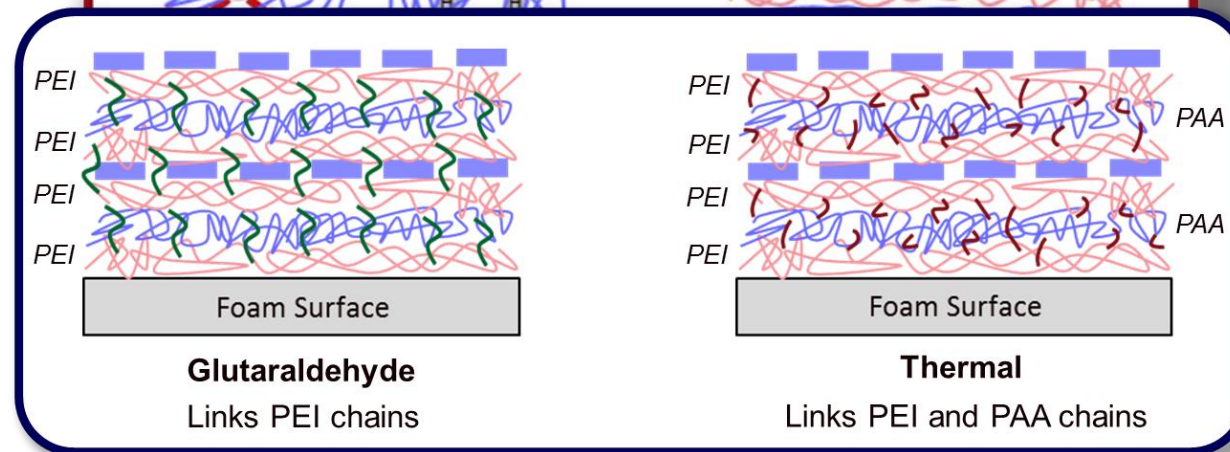
Loss of mechanical properties
major challenge for application
Coating transitions from
in biomaterials
stiff material to material as
flexible as polyurethane
Recovery from soft state
could be utilised for actuation
outside of biomaterials

Mechanism of Mechanical Property Loss



Water Distribution in Multilayers of Weak Polyelectrolytes^[1]

Proposed Solution:



[1] Tanchek et al. Langmuir. 2006;22(11):5137–43.

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Two-level factorial design of experiments (DoE) to investigate crosslinking effect

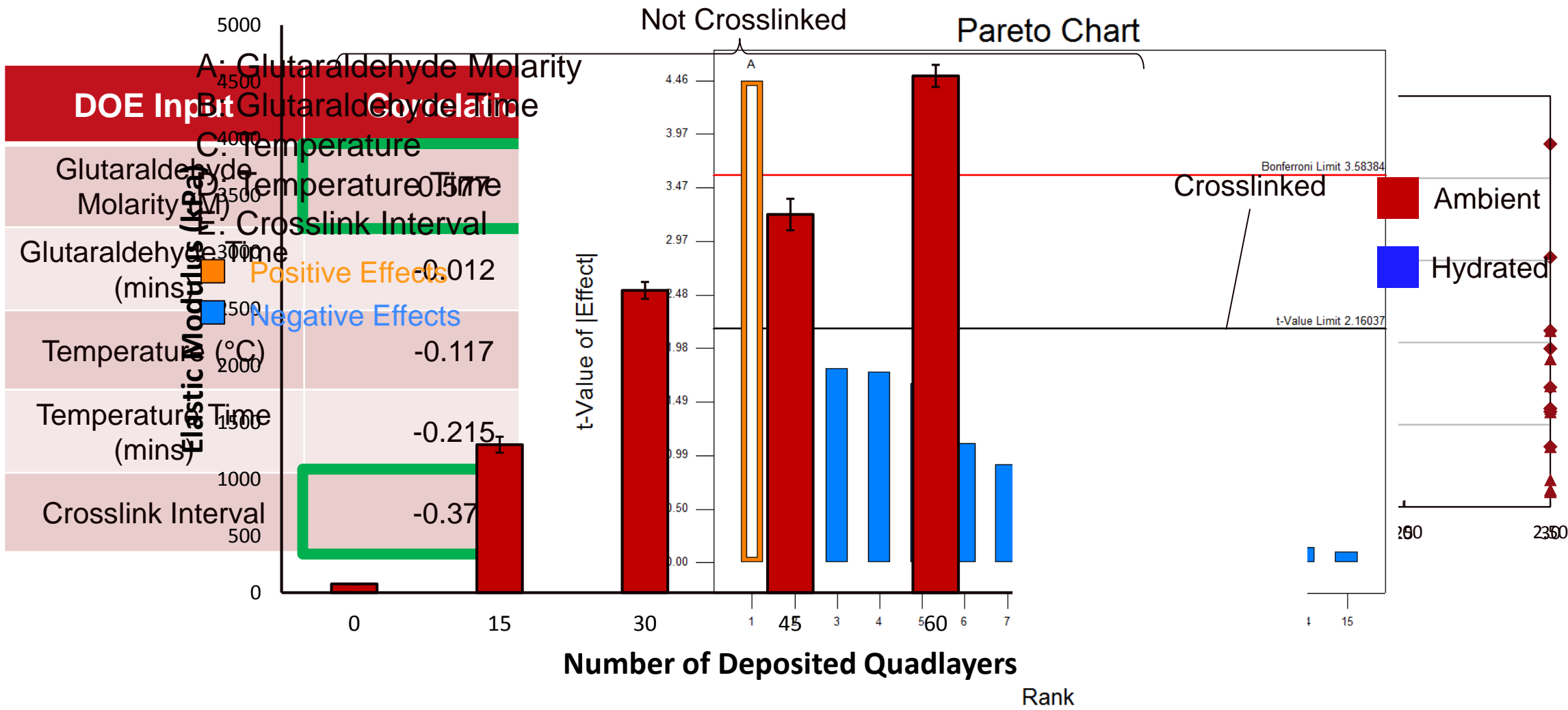
Inputs:

- | | | |
|--------------------------------------|-------------|------------|
| • Glutaraldehyde molarity (M) | 0.00 - 2.50 | M |
| • Glutaraldehyde time (mins) | 30 - 300 | mins |
| • Thermal treatment temperature (°C) | 0 or 120 | °C |
| • Thermal treatment time (mins) | 60 - 1500 | mins |
| • Crosslink treatment interval | 5 or 30 | quadlayers |

Outputs:

- | | |
|----------------------------------|---------------------------------------|
| • Ambient elastic modulus (kPa) | • Coating thickness (μm) |
| • Hydrated elastic modulus (kPa) | |

Crosslinked Coated Foams Hydrated Testing



- Mechanical contribution of (PEI/PAA/PEI/Nanoclay) coating is negligible upon submersion in DI water
- Mechanical properties of coating fully recover to match elastic modulus under ambient conditions, after desiccation
- Effects of hydration on coating analogous with **water plasticisation** as described by Tanchak et al.^[1]
- Chemical crosslinking of primary amine groups between PEI layers is the main factor for retention of mechanical properties when hydrated
 - » Effect of thermal temperature
 - » Effect of thermal time
 - » Effect of glutaraldehyde time

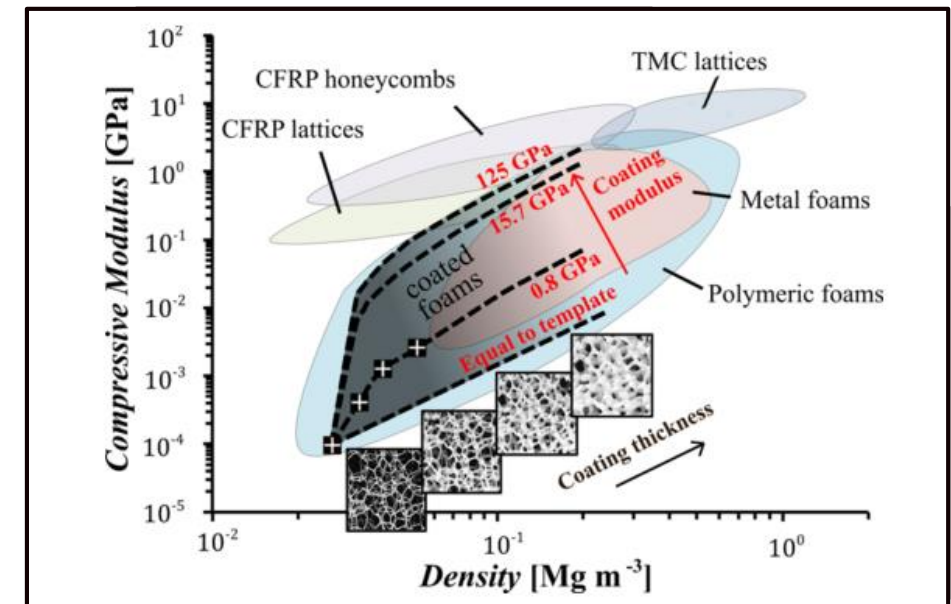
Not significant

 - » Effect of glutaraldehyde molarity
 - » Crosslink point

Significant
- Crosslinking improved retention of elastic modulus in water by up to 45%, further improvements expected after DoE optimisation

[1] Tanchek et al. Langmuir. 2006;22(11):5137–43.

- Optimised crosslinking experiment based on DoE analysis
 - » Confirmation and validation of DoE analysis
 - » Confirmation of crosslinking activity
- Compile results alongside Ziminska et al. Ashby-Gibson model adaptation
 - » Predict potential hydrated elastic modulus



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